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EVALUATION OF A SPLIT-FLOW ELUTRIATOR USED IN THE DETERMINATION OF AIRBORNE DUST CHARGE DISTRIBUTIONS

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by

M.G. Grenier* and K. Butler**

ABSTRACT

Two Split-Flow Elutriators (SFE) originally designed in Scotland at the Institute of Occupational Medicine were built and evaluated at the Elliot Lake Laboratory. These units when used in conjunction with a high-voltage power supply and optical particle counters will help determine the airborne dust electrical charge distribution. Knowledge of the level of charge on industrial dust is useful from two standpoints. First, charges on respirable dust may affect the site of lung deposition, and second, efficiency of some dust sampling instruments may also be affected by this parameter. Although some instruments are commercially available to determine dust charge distribution in the laboratory, these are rarely rugged enough to be used in the field. The evaluation performed here demonstrates that the SFE tested is rugged, well designed, and therefore well suited for field work.

Key words: Mine dust; Electrical charge distribution; Dust sampling.

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ÉVALUATION D'UN ÉLUTRIATEUR À ÉCOULEMENT DIVISÉ UTILISÉ POUR DÉTERMINER LA RÉPARTITION DES CHARGES DANS LES POUSSIÈRES EN SUSPENSION DANS L'AIR

par M.G. Grenier* et K. Butler**

RÉSUMÉ

Deux élutriateurs à écoulement divisé (ÉÉD) conçus à l'origine en Écosse, à l'Institute of Occupational Medecine, ont été construits et évalués au Laboratoire d'Elliot Lake. Ces unités, lorsqu'elles seront utilisées avec une alimentation haute tension et des compteurs optiques de particules, faciliteront la détermination de la répartition des charges électriques des poussières en suspension dans l'air. Il est utile de connaître le niveau de charge des poussières industrielles à deux points de vue. Premièrement, les charges présentes sur les poussières respirables peuvent influer sur le site où se déposeront ces poussières dans les poumons et, deuxièmement, elles peuvent aussi réduire l'efficacité de certains appareils de prélèvement des poussières. Bien qu'il existe sur le marché certains appareils permettant de déterminer en laboratoire la répartition des charges, ceux-ci sont rarement assez robustes pour être utilisés sur le terrain. L'évaluation effectuée ici montre que le ÉÉD est robuste, bien conçu et, par conséquent, bien adapté au travail sur le terrain.

Mots clés : Poussières de mine; répartition des charges électriques; prélèvement des poussières.

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INTRODUCTION

Airborne dust and aerosols are known to carry a number of positive or negative elementary charges (1). The amount of charge on particles usually lies between a lower and an upper limit. The lower limit is generally recognized to follow Boltzmann's distribution law. The Rayleigh limit is normally used as a guideline for upper limit values for charges on particles. This limit refers to the maximum number of charges that a given size water droplet may carry before surface tension forces are overwhelmed by charge repulsion forces and the droplet becomes mechanically unstable. Although this applies to water droplets. cases where the Rayleigh limit is exceeded for solid particles are rare in practice. Figure 1 shows these two limits graphically. Charge distribution as a function of particle size measured in most industrial environments is likely to fall between these two curves.

Charging of industrial dust to levels above the Boltzmann state may result in symmetrical (net neutral). or asymmetrical charge distributions (net negative or positive) depending on dust type and dust production mechanism. On the other hand. the presence of free bipolar ions in air will tend to progressively reduce the charge of airborne dust down to the Boltzmann limit.

Accumulated electric charges on dust particles have long been suspected of enhancing dust deposition in the alveolar regions of the lung. Recent work (2) confirms this and shows that there exists a threshold charge level dependent on particle size which. when exceeded. enhances alveolar deposition by induction of image charges on nearby lung tissue. It has also been advanced that space charge repulsion may affect lung deposition. The above study and theoretical work performed elsewhere (3) suggest. however. that space charge repulsion is not likely to play a significant role unless aerosol concentrations exceed 1×10^5 particles/cm^3.

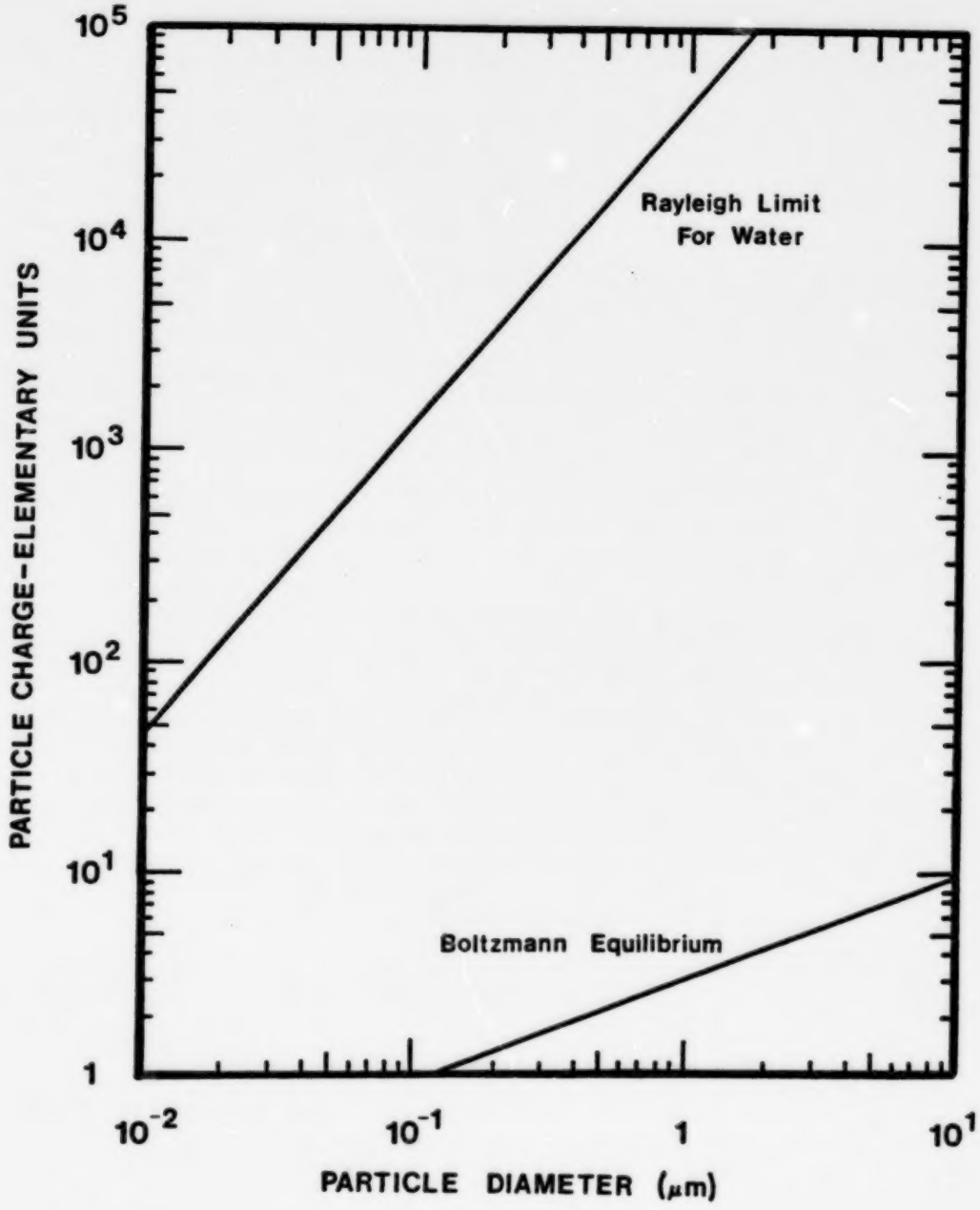

Fig. 1 - Theoretical upper (Rayleigh), and lower (Boltzmann), limits of airborne dust charge distribution.

The assessment of dust charge distribution is also important as the performance of airborne dust samplers may be affected by excess charge carried by dust particles. In addition to losses by sedimentation. impaction. turbulent deposition and diffusion. dust particles may be captured by tubing or sampler walls by image charge forces or space charge precipitation. These phenomena are not negligible and are especially noticeable in samplers or tubing made from non-conductive materials (4.5).

The need to assess the charge distribution of aerosols has led to the development of several types of instruments that have been described in detail elsewhere (6). Most commercially available instruments are bulky and very sensitive to the rugged environments encountered in industrial surroundings.

The Split-Flow Elutriator (SFE) developed by the staff at the Physics Branch of the Institute of Occupational Medicine in Edinburgh. Scotland (7) is designed to operate under more rugged conditions. The SFE when used with size discriminating dust counters is able to simply and elegantly establish the charge distribution of airborne particles of both polarities. The SFE developed in Scotland is not available on the market. and therefore has been duplicated at the Mining Research Laboratory in Elliot Lake. Ontario. Canada. The SFE is used in conjunction with a particle counter which allows particle mobility and charge to be deduced simultaneously in six preset size ranges.

The aim of this report is to evaluate the two SFEs built at the Elliot Lake Laboratory and to assess their performance in laboratory and industrial environments.

SPLIT-FLOW ELUTRIATOR CONSTRUCTION

The elutriator is shown in side and top cut-away views in Figure 2. The instrument consists of two halves that make up the main body. in addition to the flow-splitting end cap and two stainless steel plates. The main body and

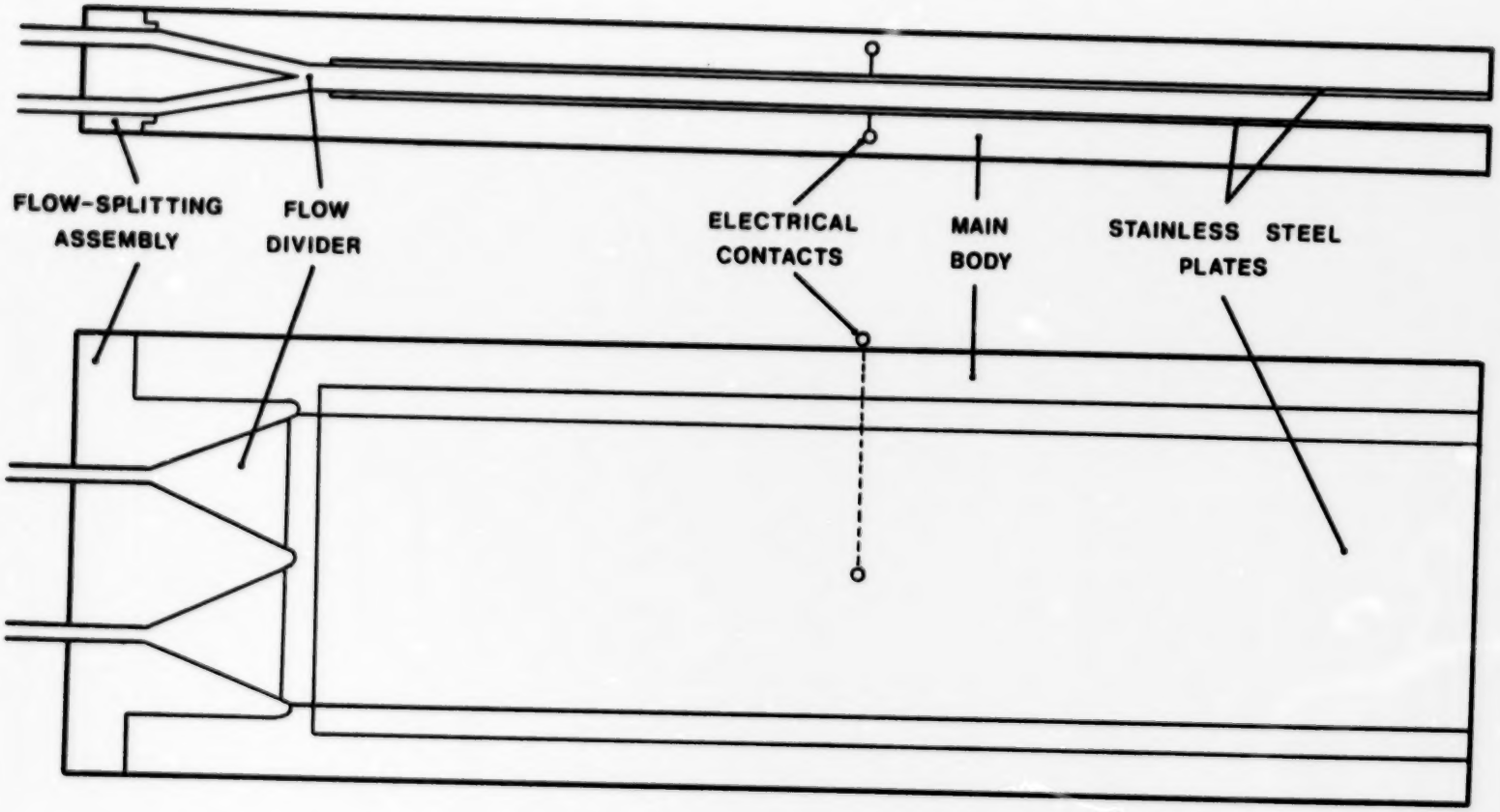

Fig. 2 - Top and side cut-away views of the split-flow elutriator.

the flow-splitting assembly are made from high-resistivity laminated resin sheets. The potential difference across the plates is applied through spring loaded contacts on the centre of the plates.

The design of the flow-splitting assembly is attractive for two reasons. First, referring to the bottom portion of Figure 2, the elutriator channel is gradually reduced into two funnel shaped exit ports. This is preferable to one exit port since it helps reduce the mass and size of the instrument. Second, and more importantly, the flow divider (seen in the top drawing of Figure 2) splits the elutriator channel into two, thus allowing the instrument to be used under two specific modes of operation. One, in which the elementary charge distribution of the dust cloud is established without discriminating between polarities (Type A runs), and the other where distribution of both polarities are being measured (Type B+ and B- runs). Operating procedures for both types of experiments are outlined below.

The elutriator channel (lined with steel plates) measures 35 cm in length (l), 8.6 cm in width (w), and 0.8 cm in height (2b). The size of the channel was designed to accommodate a flow rate of approximately 3 L/min. This value defines an elutriator clearance time of less than 5 sec and laminar flow conditions within the channel. Under these conditions, for industrial dust clouds, a power supply adjustable between 0 and 5000 VDC was found to adequately reduce dust penetration to particle counters. The elutriators were used in conjunction with an EG & G model 459, 5 kVDC power supply, and Mono Research Limited optical particle counters (modified HIAC/ROYCO model 4100). These counters were ruggedized and modified for use in environments with high dust concentrations. These particle counters measure dust concentration in six preset dust size intervals.

OPERATION AND DATA MANIPULATION

The Split-Flow Elutriator may be used under two types of operating conditions. These are shown schematically in Figure 3. Figure 3a shows the type A sampling configuration. This experiment is simple and is used for the routine assessment of electrical charge distribution without polarity distinction. This configuration, however, does not use the elutriator at its full potential. Type A runs, therefore, should be used mainly when type B runs have shown that the total airborne dust charge is symmetrical (net neutral). Figure 3b shows the type B+ or B- configuration. In a B+ configuration the aerosol sampler is connected to the two ports on the side of the knife edge divider close to the positive stainless steel plate. The type B+ run is used to establish the mobility of negatively charged particles. In this configuration, the other two ports have to be drawing air at a flow rate that matches that of the particle counter. This may be accomplished by using a good quality electronic sampling pump. Type B- runs may then be conducted by reversing the polarity or switching the pump and the sampler.

For the evaluation reported here, two aerosol samplers were available. This enabled both B+ and B- runs to be conducted simultaneously. The advantages of having two counters are twofold. First, the flow rates were well matched at all times, and also it helped avoid complications arising from dust concentration and charge conditions changing between B+ and B- runs since both could be performed simultaneously.

The data analysis for the SFE system is straightforward, hence the detailed theory behind the instrument will not be outlined. The reader interested in the detailed theoretical background is referred to the original work by Johnston (7).

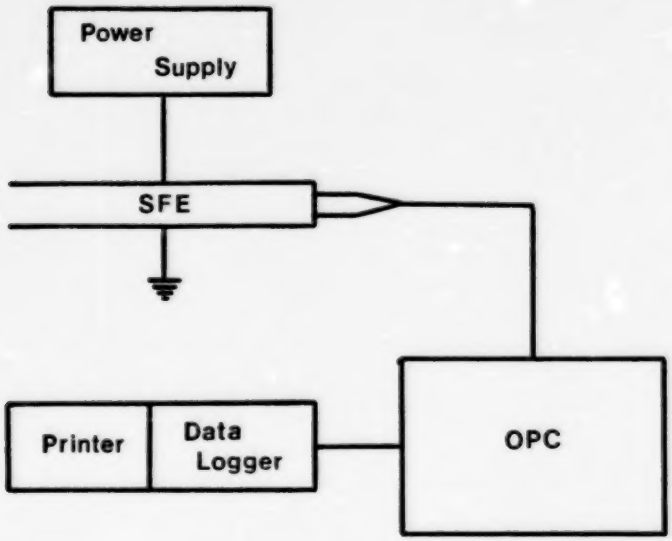

Fig. 3a - Type A sampling configuration.

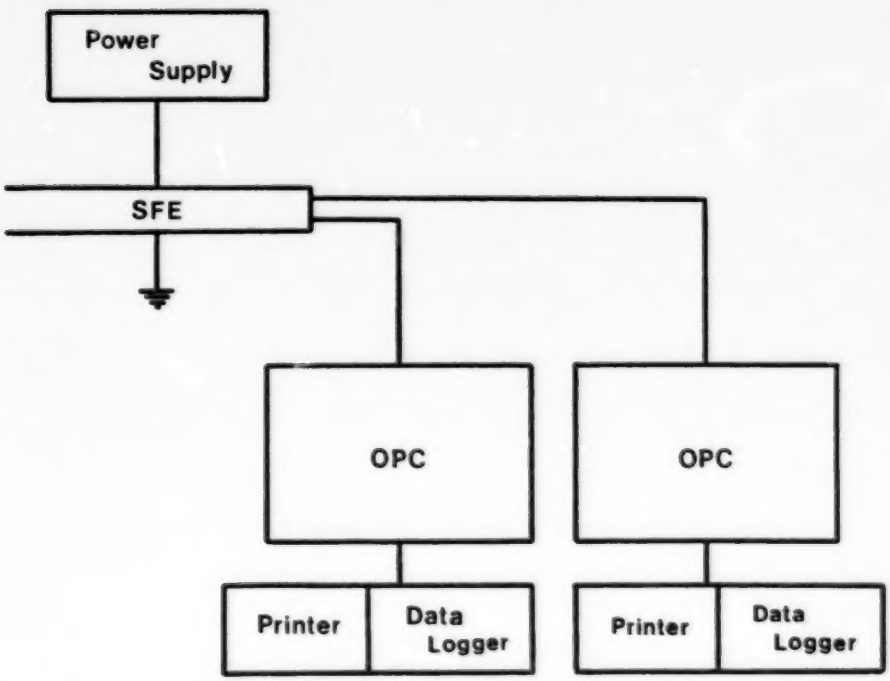

Fig. 3b - Type B sampling configuration.

TYPE A CONFIGURATION

Type A runs are used to establish elementary charge distribution of airborne dust clouds without polarity distinction. In this mode all four sampling ports in the flow-splitting assembly are connected together and are sent to one of the optical particle counters (OPC). The other counter is sampling in a location near the SFE entrance to ensure that the dust concentration in the six size ranges are constant during the voltage sweep. After both counters have been put in operation the SFE is positioned on edge (to avoid gravitational deposition biases) and the power supply is connected to it. The polarity is of no consequence in the A run configuration.

Once the counters are operating and the airborne concentration is constant on the unconnected OPC the actual run may begin. Because the dust penetration curve does not decrease linearly with increased voltage. it is desirable to increase the voltage slowly (increments of 50 or 100 volts) at the beginning of the run (when penetration drops rapidly with voltage). and more rapidly (increments of 500 or 1000 volts) at the end of the run. Typically. runs need to be conducted at voltages up to and over 3000 volts.

Prior to the run the OPCs are programmed to sample every 20 to 60 sec. Initially two or more samples are obtained at zero voltage with the printout being examined to ascertain that there is a stable concentration in all six channels. Following this the voltage is increased to the first chosen increment and typically two samples are collected at every voltage step. Normal practice is to return the voltage to zero between voltage increments to ensure dust concentration stability throughout the run. Voltage is increased until penetration of dust in the SFE is reduced to within 5% of zero or until penetration does not decrease any further. A complete run should be conducted over a period of no more than 10 min and should be repeated several times to ensure reproducibility.

Once the run is completed, concentration data as a function of voltage may be tabulated as in Table 1. Penetrations are normalized to zero volt concentration. The sizes that are shown in Table 1 refer to the mean value of the size range associated with each OPC channel. For each size range the penetration is then plotted as a function of voltage (see Figure 4). A tangent to the curve passing through the 50% penetration points is then drawn and the voltage (V_o) thus defined is used to calculate the median electrical mobility of particles in that size range. The mobility is calculated from:

$$\mu = \frac{bF}{V_o\ w\ l} \qquad (7,8) \qquad \text{Eq 1}$$

where, μ is the electrical mobility ($m^2\ V^{-1}\ s^{-1}$)

b is one half the SFE channel height (0.004 m)

F is the OPC flow rate ($5.0 \times 10^{-5}\ m^3\ s^{-1}$)

w is the channel width (0.086 m)

l is the channel length (0.350 m)

V_o is the above defined voltage (V)

The median number of elementary charges may then be calculated from:

$$m = \frac{3\Pi\ \mu\ \eta\ d}{eC} \qquad \text{Eq 2}$$

where, m is the number of elementary charges

μ is the electrical mobility ($m^2\ V^{-1}\ s^{-1}$)

η is the air viscosity ($\sim 1.8 \times 10^{-5}$ kg $s^{-1}\ m^{-1}$)

d is the mean particle diameter (m)

e is the unit electronic charge (1.602×10^{-19} coulomb)

C is the Cunningham slip correction (~1).

Therefore, using Equations 1 and 2, and substituting for known constants and variables, we may easily obtain the median number of elementary charges from the mean particle diameter and the 50% cut-off voltage as follows:

$$m = 7.036 \times 10^3\ \frac{d}{V_o} \qquad \text{Eq 3}$$

Table 1 - Typical dust penetration data normalized to the zero volt concentration in each size range.

Voltage	Penetration for Various Sizes of Dust Particles				
	1.00 μm	1.75 μm	2.75 μm	4.25 μm	7.5 μm
0	1.00	1.00	1.00	1.00	1.00
100	0.82	0.74	0.67	0.62	0.65
200	0.60	0.49	0.39	0.35	0.34
300	0.45	0.27	0.19	0.15	0.18
400	0.33	0.24	0.18	0.16	0.17
600	0.23	0.14	0.11	0.09	0.12
800	0.17	0.12	0.09	0.09	0.14
1000	0.13	0.08	0.06	0.05	0.07
2000	0.07	0.05	0.04	0.03	0.04

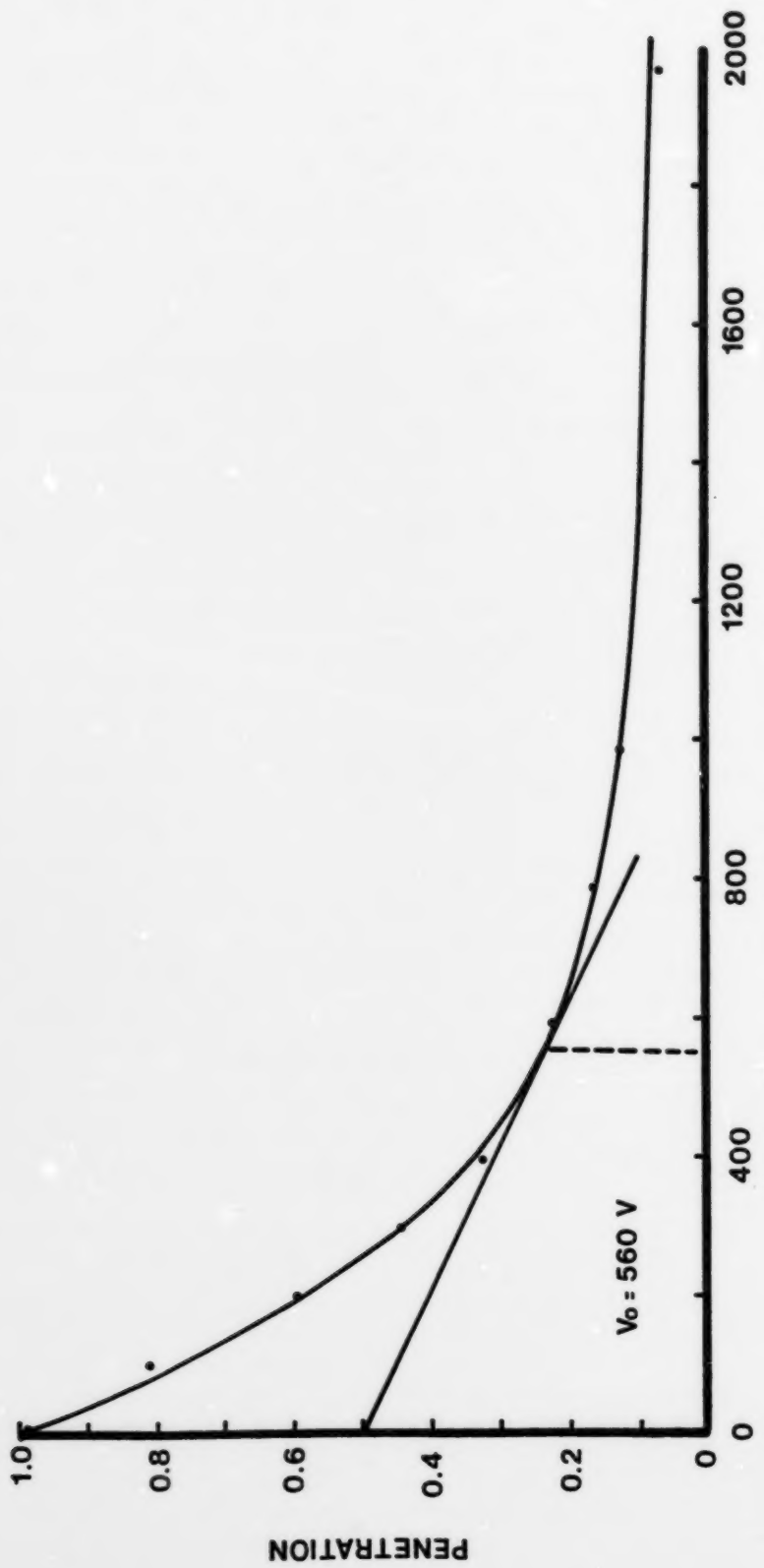

Fig. 4 - Graphical representation of the tangent method used to determine the critical voltage (V_o) at the 50% penetration point.

where. d is the mean particle size (μm)

V_o is the voltage as defined in Eq. 1 (V).

By repeating the above operation for the remaining OPC channels (using Table 1 data) it is possible to determine the median number of elementary charges as a function of particle size. These values may be plotted. as shown in Figure 5. to give the dust cloud charge distribution. In Figure 5. the data from Table 1 is represented by the topmost curve labelled Lime Crushing Plant.

TYPE B+ AND B- CONFIGURATIONS

Type B runs are used to establish the relative amounts of negatively charged and positively charged particles in a dust cloud. Experience (1.9) has shown. however. that most industrial dusts are symmetrical (net neutral). Asymmetrical clouds are more likely to be found in laboratory settings where the dust dispersion system or conditioning of aerosols creates an artificial charge imbalance.

Both types of B runs can be conducted simultaneously with the help of two OPCs. The B+ run examines negatively charged particles by connecting one of the OPCs to the side of the knife edge divider close to the positively charged stainless steel plate and vice versa for the B- run. Otherwise. data are gathered and penetration curves are analyzed more or less as described in the previous section.

LABORATORY AND FIELD TESTING OF THE SPLIT-FLOW ELUTRIATORS

The two elutriators were first evaluated in-house in an artificial atmosphere. These tests were aimed at establishing that both elutriators gave similar results. and also that both channels were symmetrically situated about the central knife-edge divider. The need for a properly positioned knife-edge

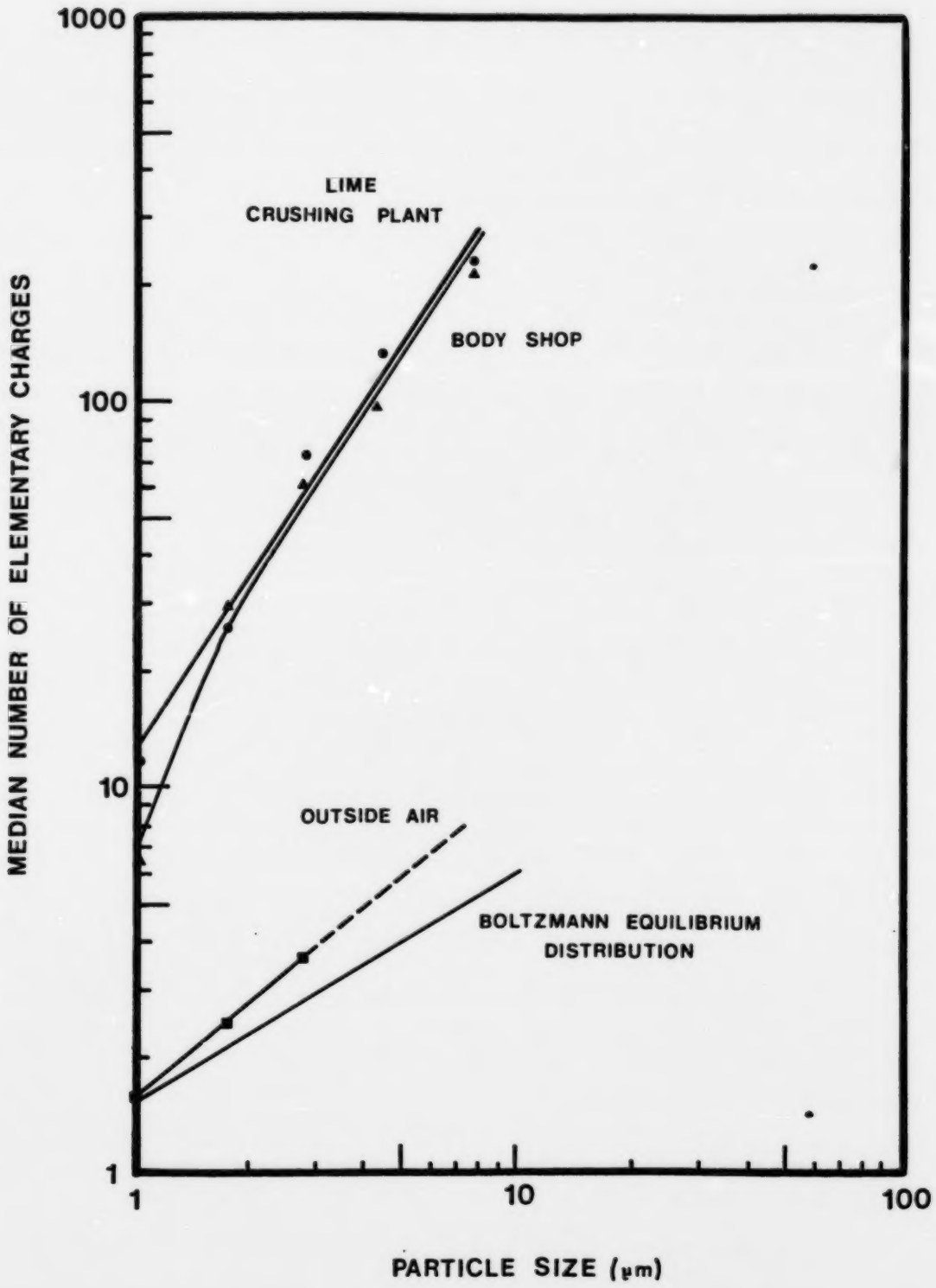

Fig. 5 - Results of experiments conducted to measure the charge distribution of dust at a lime crushing plant (•), at a car body shop (▲), and in calm outside air (■).

is critical and much of the theory behind the operation of the instrument depends on sound construction. The second phase was undertaken in the field in order to test the elutriators under natural extremes of low and high levels of charge distribution on airborne dust.

LABORATORY TEST

These tests were conducted in a large environmental chamber designed to calibrate radiation monitoring instruments. Sodium chloride aerosol was injected into the room with the help of a TSI Inc. Aerosol Generator. The mean size of the aerosol was approximately 0.1 μm. as measured by a TSI Inc. Differential Mobility Particle Sizer. The modified ROYCO counters were not used at this stage. Instead. the more portable and simpler Rich model 200 Condensation Nuclei Counter was used to monitor the total aerosol penetration through the elutriators. Type B runs were conducted with the help of a Gilian model 513 electronic sampling pump.

The elutriators were first connected in an A configuration and concentration data were recorded as the voltage was increased to 3000 V in steps. The Rich counter was sampling at a flow rate of 2.2 L/min. Normalized penetration data are shown in Figure 6 for elutriators 1 and 2. These curves show excellent agreement with penetration values differing on average by 2.5%. The elutriators were then tested under both B configuration situations. The Rich counter was used on one channel while the flow was matched exactly on the other channel using an electronic pump. Normalized penetration data for both elutriators showed good agreement for this case as well. with less than 2% difference on average between corresponding penetration data points.

The third part of the laboratory investigation was not designed to compare elutriators 1 and 2. but rather was aimed at showing that both instruments were symmetrical about the knife-edge. In this part of the study. the following reasoning was used. If a B- run is conducted. then by switching

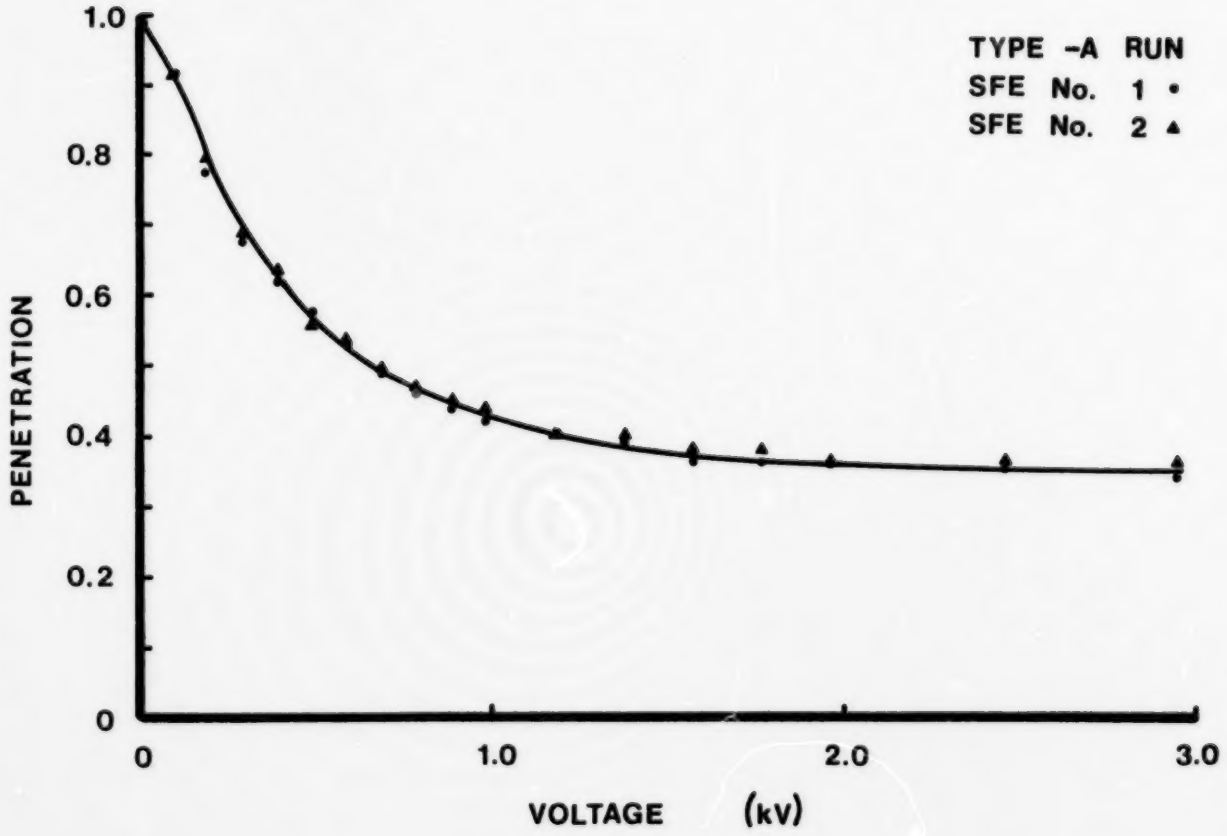

Fig. 6 - Results of Type A runs conducted in controlled laboratory conditions for both elutriators.

both the polarity and the positions of the sampler and the counter. the elutriator is still in a B- configuration. If. then. there were any major differences between the penetration curves thus obtained it can be assumed that there are flaws in the instrument design or construction. This presupposes of course. that the charge distribution has not changed during the experiment and the flow rates in both instances are well matched.

Figures 7 and 8 show the results of B- runs conducted in this fashion for elutriators 1 and 2. with average differences in penetration values of 2.6% and 2.3%. respectively. From these results and the A and B run inter-comparisons conducted earlier it was assumed that the instruments were sound and could now be tested in field situations.

FIELD TESTS

This part of the evaluation was conducted in order to establish that the SFE could perform under low and high charge distribution situations. These tests also serve to demonstrate that the elutriator and the associated equipment could withstand harsh field conditions.

Several tests were performed in calm morning air of a small Northern Ontario community. Tests were also performed at a car body shop. and at a lime crushing plant. where it was hoped that operations such as grinding and crushing would lead to high charge levels on airborne dust. The results of these tests are shown in Figure 5. and it can be seen that data for outside air lie very close to the Boltzmann equilibrium limit as was expected. On the other hand data obtained from the body shop and the lime crushing plant show high charge levels (up to 220 elementary charges on 7.5 μm dust). comparable in magnitude to crushing operation distributions measured by Johnston at quarries in the United Kingdom (1).

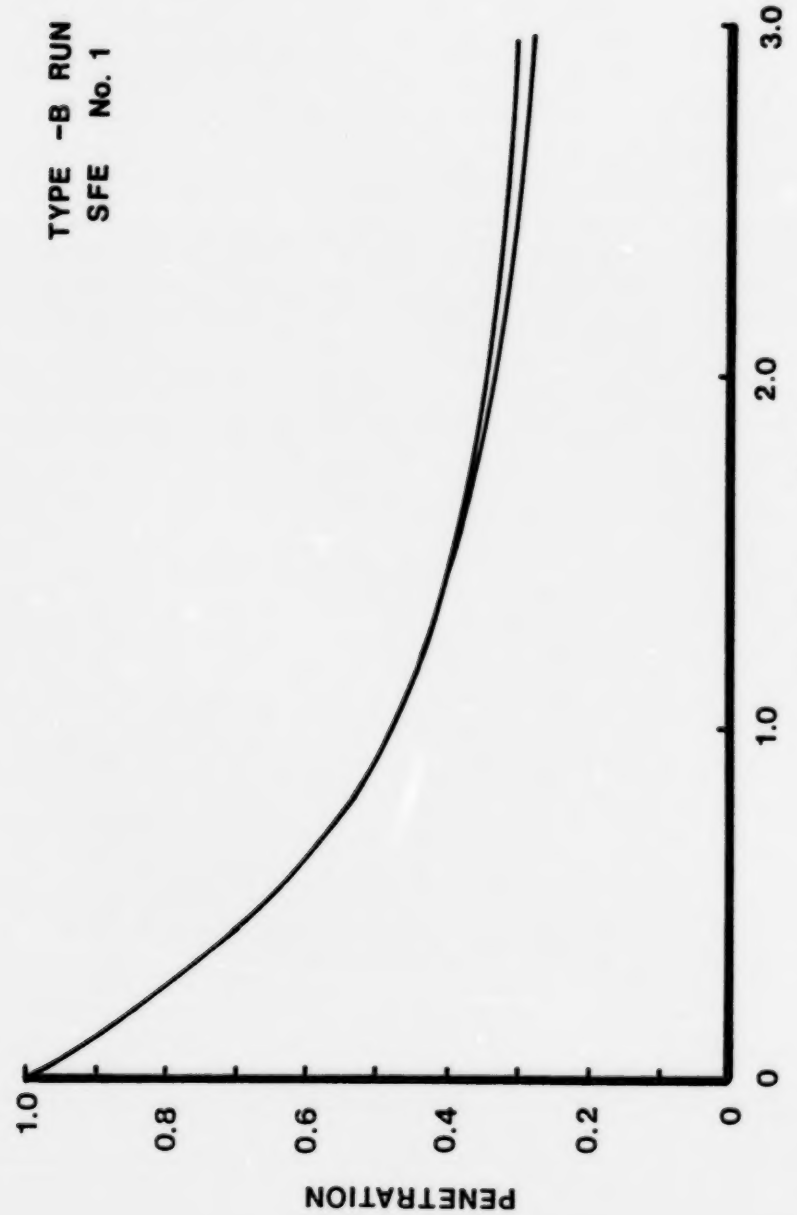

Fig. 7 - Type B(-) run tests conducted on elutriator No. 1.

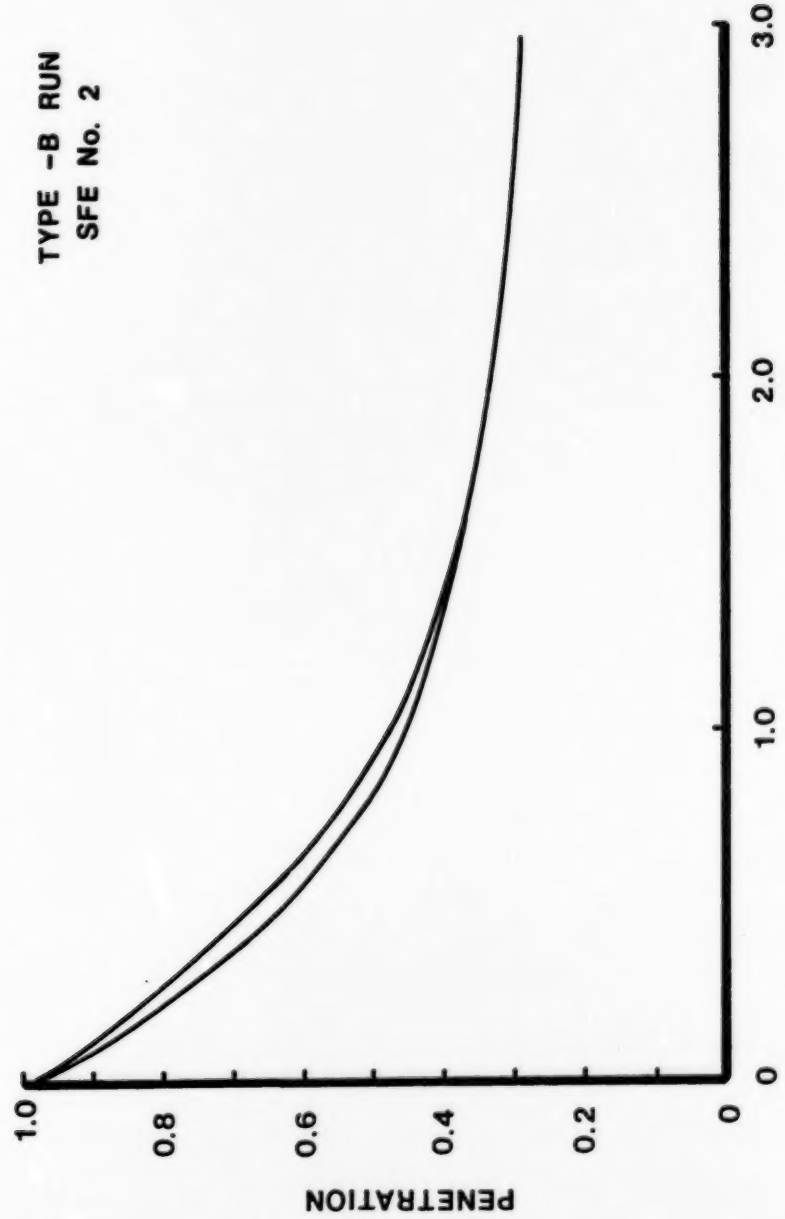

Fig. 8 - Type B(-) run tests conducted on elutriator No. 2.

CONCLUSION

The SFE designed at the Edinburgh Institute of Occupational Medicine is a practical and rugged instrument well suited for field situations. Data gathering and analysis is straightforward with the exception of the possibility of subjective errors occurring when carrying out the tangent method for determining the critical voltage. The use of two optical particle counters to simultaneously carry out the B+ and B- runs is a definite asset and reduces the risk of errors brought about by charge distribution changes between runs had these been conducted in sequence. From the tests carried out in the laboratory it can be stated that both elutriators performed properly. Results show that sampling channels are symmetrical about the knife-edge and that both instruments yield identical penetration data to within 3%.

Field data showed symmetrical (net neutral) charge distributions that fell, as expected, between the lower and upper limits defined by the Boltzmann and Rayleigh distributions. Tests conducted in calm morning air are in close agreement with the Boltzmann equilibrium curve, and charge distribution data from highly mechanized operations resemble data gathered by Johnston at similar operations in the United Kingdom.

The EG & G power supply used as part of the equipment performed well and the only possible drawback is that there is no convenient switch which can be used to reverse the polarity. The polarity may be changed by manually relocating a plugboard after removing the side access panel. The optical particle counters operated reliably except under conditions of high dust concentration where, in some cases, signs of saturation in lower size channels was evident. There are provisions for diluting the input air and determination of adequate dilution ratios are presently being calculated. Finally, the design of the elutriator and the materials used in the

construction of the unit ensure a high level of reliability. One problem in the field occurred when the cold instrument was brought underground in warm moist air. As a result condensation formed inside the elutriator channel and caused a short-circuit resulting in a power supply failure. In that case, it was necessary to dismantle the elutriator, warm the stainless steel plates to ambient temperature, remove the condensation and reassemble.

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REFERENCES

1. Johnston, A.M., Vincent, J.H. and Jones, A.D., "Measurement of electric charge for workplace aerosols": Ann Occup Hyg, vol. 29, No. 2, pp 271-284, 1985.

2. Prodi, V. and Mularoni, A., "Electrostatic lung deposition experiments with humans and animals": Ann Occup Hyg, vol. 29, No. 2, pp 229-240, 1985.

3. Yu, C.P., "Theories of electrostatic lung deposition of inhaled aerosols": Ann Occup Hyg, vol. 29, No. 2, pp 219-227; 1985.

4. Liu, B.Y.H., Pui, D.Y.H., Rubow, K.L. and Szymanski, W.W., "Electrostatic effects in aerosol sampling and filtration": Ann Occup Hyg, vol. 29, No. 2, pp 251-269, 1985.

5. Blackford, D.B., Harris, G.W. and Revell, G., "The reduction of dust losses within the cassette of the Simpeds personal dust sampler": Ann Occup Hyg,

Vol. 29. No. 2. pp 169-180. 1985.

6. Hochrainer. D.. "Measurement methods for electric charges on aerosols": Ann Occup Hyg. vol. 29. No. 2. pp 241-249. 1985.

7. Johnston. A.M.. "A semi-automatic method for the assessment of electric charge carried by airborne dust"; Ann Occup Hyg. vol. 14. No. 5. pp 643-655. 1983.

8. Hurd. F.K. and Mullins. J.C.. "Aerosol size distribution from ion mobility"; J Colloid Science. vol. 17. pp 91-100. 1962.

9. Grenier. M.G. "Charge distribution of dust in underground hard rock mines": Division Report in preparation. CANMET. Energy. Mines and Resources Canada. 1988.